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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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DYNAMOMETER-STAND INVESTIGATION OF THE MUFFLER USED IN THE DEMONSTRATION OF LIGHT-AIRPLANE NOISE REDUCTION

By K. R. Czarnecki and Don D. Davis, Jr.

Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

As part of a general investigation directed toward the reduction of airplane noises, tests were made on a ground dynamometer stand of a muffler designed for an army liaison-type airplane. The ground tests indicated that a reduction of 10 to 15 decibels was to be expected from this muffler over the range from 1650 to 2790 rpm and that an additional reduction of 5 decibels was to be expected at some engine speeds from the installation of a long tail pipe with an upward bend. This reduction was substantiated by flight tests. The calculated attenuation characteristics of the muffler are also presented. The experimentally determined low-frequency cut-off and upper pass frequencies agreed with the calculated values. Further reductions in over-all noise level for the engine appeared possible only through quieting of intake and engine-clatter noises. The back pressures of the airplane with muffler were about a third higher than those for the unmodified airplane at 2790 rpm and were lower at lower engine speeds. The power variations due to these back-pressure changes were small.

INTRODUCTION

As part of a general investigation directed toward the reduction of airplane noises, particularly those produced by the personal owner type of airplane, a theoretical and experimental investigation is being conducted by the Langley Laboratory of the National Advisory Committee for Aeronautics of the methods of muffler design. The study was undertaken as a result of recent developments in propeller noise reduction which make possible reduction of airplane propeller noise to a level considerably below that of the engine itself and as a result of the fact that a reduction in noise level of one without a reduction in that of the other usually does not result in any substantial reduction in over-all noise level. Several theoretical methods, in particular those of electrical analogy technique, can be used to design mufflers, but in practice much difficulty has been experienced in correlating theory with experiment on an actual engine, usually because of excessive noise interference during testing from sources other than the engine exhaust. Lack of understanding of the reasons for poor correlations makes it extremely difficult to design a muffler having the desired attenuation characteristics without much empirical experimentation. Also, at the present time the lack of basic information regarding what noise level is acceptable to the public handicaps the designer. The object of this research is to gain an understanding of the main principles involved and to reduce muffler design to a more rational basis.

As part of this study an experimental investigation has been made of a series of exhaust mufflers installed on a typical six-cylinder light-airplane engine. The results of the tests of a low-frequency pass exhaust-noise filter, which was later installed on a light airplane in conjunction with a relatively "quiet" five-blade propeller for flight tests (reference 1), are given in the present paper. The tests were conducted with the engine mounted, with propeller removed, in a ground dynamometer stand. Over-all noise levels and noise spectrums were determined over a range of engine speeds with and without the muffler. Some measured back pressures, engine power variations, and a brief comparison between the theoretical and measured attenuation characteristics of the muffler are included.

It is stressed that this muffler is not an optimum design in any respect and is only intended to indicate the possibility, not feasibility, of quieting engine exhausts with reasonable back pressures. Neither the size nor the type of the muffler is intended to be related in any way with the smallest or most efficient muffler that can be designed for the particular engine used in this investigation.

MUFFLER AND ENGINE

Consideration of the problem of exhaust silencing leads to the conclusion that the ideal muffler is one which eliminates all of the pulsating or "alternating current" flow while allowing the steady or "direct current" flow to pass through the exhaust pipe unopposed. An acoustical device analagous to an electrical low-pass filter would meet these requirements. In reference 2, one method of designing such a device is discussed, and experimental evidence of its effectiveness is presented. With this reference as a guide, a muffler was designed for the quiet-airplane demonstration. The details of the design method are presented in appendix B.

The muffler was designed to begin reducing the over-all exhaust noise level when the engine speed was raised to about 1400 rpm and to give a theoretical attenuation of at least 15 to 20 decibels at engine speeds of 1650 rpm or over. The exhaust pipe was chosen to have an area about the same as the sum of the areas of the two original exhaust manifolds, inasmuch as a smaller area with the length of tail pipe required for the actual flight installation would have resulted in excessive back pressures at high engine speeds. These design conditions resulted in the muffler shown in figure 1. The muffler was constructed of mild-steel tubing and sheet, welded together to form two tandem cylindrical resonance chambers, each located concentrically about the internal tube that served to guide the exhaust gases. The resonance chambers each were 25 inches long and approximately 12 inches in outside diameter. The exhaust pipe was $2\frac{3}{4}$ inches in outside diameter and had

a $\frac{1}{16}$-inch-thick wall. Connection between the resonance chambers and the exhaust pipe was obtained by means of a section of perforated tubing, 8 inches long, welded into the exhaust pipe at the forward end of each chamber. A 6-inch length of exhaust pipe was left protruding at each end of the muffler to provide means of attaching the muffler to the rest of the exhaust system. A tail pipe terminated by an upturned elbow, simulating the flight installation, was installed for some of the ground tests. No attempt was made to design the smallest possible muffler; physical size was a secondary consideration because this muffler was intended to demonstrate the possibility, rather than the practicality, of airplane-engine silencing.

The theoretical attenuation of this muffler, as calculated by an approximate formula, is shown in figure 2. Three theoretical curves are plotted, one for each of the engine speeds at which measurements of sound intensity and frequency were made. In order to obtain the curves, estimation of the probable exhaust gas temperatures was necessary at these engine speeds.

The engine, which powers the test airplane, is a direct-drive, four-stroke, opposed, six-cylinder engine of 435-cubic-inch displacement and rated at 185 horsepower at 2550 rpm at sea level. The engine is equipped with two exhaust manifolds, one on each side of the engine as shown in figure 3. In order to install the muffler the cones with the longitudinal slits at the ends of the exhaust pipes were removed and the two manifolds brought together to a common pipe to which the muffler was welded. (See fig. 4.)

APPARATUS AND TECHNIQUES

A photograph of the dynamometer setup is presented in figure 5. On the right-hand side of the photograph may be seen the engine and cowling which were taken as a unit from the test airplane. Inasmuch as the propeller was removed for this series of tests, the power from the engine was absorbed by means of an electric induction motor run as a generator with the power being fed back into the line. A variable-frequency alternator was utilized to absorb the power and supply exciting current to the motor. The motor is rated at 266 horsepower at 3500 rpm and has power-speed characteristics similar to those of the engine at full-throttle operation. Cooling air for the cylinders and oil cooler was supplied by means of a blower installed within a duct that guided the flow to the engine and oil-cooler cooling-air inlets.

The test airplane instruments were used to check engine operation except that engine speeds were determined with a combination of magnetic-drag airplane tachometer generator and indicator, and thermocouples were installed in the spark-plug gaskets of the spark plugs nearest the exhaust ports to insure that the engine was not overheated during the tests. Engine back pressures were determined with a micromanometer connected to a static pressure tap installed in the exhaust pipe from

the left rear cylinder about 8 inches from the exhaust port. Variations in engine power between the different configurations were determined by electrical measurements of the output and losses of the dynamometer.

A General Radio Company sound-level meter, type 759-A, was used to measure the over-all noise levels and a General Radio Company sound analyzer, type 760-A, was used to determine the noise spectrums. All noise levels were measured in decibels of sound intensity referred to the Acoustical Society of America standard base pressure level of 0.0002 dyne per square centimeter.

Noise-level measurements and spectrum analyses, with readings taken at multiples of one-half the firing frequency, were made at a point 50 feet from the ends of the unmodified exhaust stacks on a line 135° to the right and rear of a line running forward in the plane of symmetry of the engine. The noise-level meter and spectrum analyzer were placed on a board which rested directly upon the ground. No corrections for ground reflections have been applied to the data presented in this paper.

Over-all noise levels were measured over a range of engine speed from 1000 to 2790 rpm for three configurations: the engine with the unmodified exhaust stacks, the engine with muffler, and the engine with the muffler and a long tail pipe (10.5 ft) bent upward near the end. The last configuration approximates the actual flight installation. All measurements were made with full-open throttle. Spectrum analyses were made for all configurations at 1650 and 2000 rpm and for the first two configurations at 2790 rpm. Engine back pressures and power outputs were measured at these same three speeds. After the completion of these ground tests, the muffler was installed in the airplane for flight testing.

The theoretical attenuation characteristics of the muffler were computed by the electrical analogy methods of reference 2, with the use of estimated exhaust gas temperatures. The design equations are presented in appendix B.

RESULTS AND DISCUSSION

Ground Tests

Over-all noise levels.- A comparison of the over-all noise levels measured for the various configurations is given in figure 6. The data indicate that the over-all noise level of the engine at full throttle with the unmodified exhaust stacks was about 83.5 decibels at an engine speed of 1000 rpm, increased rapidly with engine speed to about 97 decibels at about 1650 rpm, and thereafter remained approximately constant. Both theory and experimental results not given herein indicate that an increase in the effectiveness of the exhaust manifolds as mufflers with an increase in the frequency of the noise is responsible for the leveling off of the curve at the higher engine speeds. Tests of airplanes with stub stacks

show noise levels 10 or more decibels higher than noise levels for similar airplanes with ring manifolding.

With the muffler alone installed, the over-all noise level was reduced by almost 15 decibels at 1650 rpm and by approximately 10 decibels at 2790 rpm, the maximum speed investigated. The maximum attenuation appeared to occur at about 1800 rpm. Below this engine speed the effectiveness of the muffler decreased until at 1000 rpm practically no attenuation was obtained. This loss in muffler effectiveness can be predicted from the theoretical curves of figure 2. A rapid decrease in attenuation occurs as the frequency decreases to 70 cycles per second, and below this point no attentuation by the muffler is expected. When the engine speed is decreased to and below 1400 rpm, the fundamental firing frequency approaches and drops below 70 cycles per second and is, therefore, attenuated less and, finally, not at all. Inasmuch as most of the sound energy is concentrated in this fundamental note and its low-order harmonics, as is shown subsequently, a rapid deterioration of the over-all muffler effectiveness occurs as the engine speed is reduced so that the frequency of the fundamental note drops below the design end point or cut-off frequency. The increase in over-all noise level encountered with increased engine speeds above 1400 rpm with the muffler installed is ascribed mainly to the fact that the intake noise level and engine-clatter noise level (level of gear, valve, piston-slap, and other noises radiating from the sides of the engine) increase with speed.

With the long tail pipe added to the muffler a further reduction in over-all noise level of about 5 decibels was obtained at 1650 and 2790 rpm, but none at 2000 rpm. Calculations indicate that at the engine speed of 2000 rpm the wave length of the fundamental note is about twice the length of the long tail pipe behind the muffler; therefore, the tail pipe resonates and the effectiveness of the complete configuration is decreased at this engine speed. Additional results not shown here indicate that the minimum over-all noise level obtainable for this engine with a muffler lies along a curve approximately parallel to and 5 decibels below the curve for the muffler without the tail pipe. Any further noise reduction requires a quieting of the intake noise and engine clatter.

Noise spectrums.- Noise spectrums of the engine with and without the muffler are presented in figure 7. These spectrums are quantitatively applicable only to the engine used in this investigation, although other six-cylinder engines of about the same horsepower and speed would probably have spectrums of somewhat similar shapes. At all speeds, the loudest component of the noise of the unmuffled engine occurred at the fundamental firing frequency of the engine (speed (rpm) times 3/60 cps) and most of the sound energy was concentrated at this frequency and its low-order harmonics. This fact becomes more evident if it is considered that the energy in a 100-decibel sound is 10 times that in a 90-decibel sound and 100 times the energy in an 80-decibel sound and if the sound levels of the low frequencies in the spectrums shown are noted to be 10 to 20 decibels above those of the high frequencies. Conversely, it may be deduced that the reduction of 15 to 20 decibels in over-all noise level obtained with the muffler with long tail pipe represents a reduction in over-all sound energy of the exhaust noise of about 97 to 99 percent.

Installation of either the muffler alone or the muffler with the long tail pipe resulted in a reduction in the intensity of these low harmonics although the magnitude of this reduction depended greatly upon the amount of tail-pipe resonance present. The exhaust pipe ahead of the muffler and the tail pipe behind the muffler of an exhaust system resonate at certain frequencies, just as an organ pipe does, and the exhaust noise is, therefore, amplified at those frequencies. Too much significance should not be attached to the apparent attenuation in noise levels where any of the curves fall below 70 decibels because of the decrease in instrument reading accuracy and, also, because of the increased interference from engine-clatter, intake, and background noises at this noise level. Comparisons of the magnitudes of the measured and calculated attenuation values have little meaning, particularly at the higher engine speeds where intake and engine noises are quite loud, because the measured noise spectrums represent exhaust and engine noises combined, whereas the calculated attenuation curve applies only to exhaust noise. With these facts in mind, however, encouragement on at least the three following points can be obtained by making the comparisons:

(1) The predicted exhaust attenuation seems to be achieved at the fundamental firing frequency (except for the 2790 rpm case, with high engine clatter)

(2) The upper pass band or region of no attenuation, which was predicted theoretically, is quite close to the experimentally determined pass band

(3) The effectiveness of the muffler decreased rapidly at engine speeds below the speed corresponding to the calculated low-frequency cut-off.

Engine back pressures and power variations.- The results of the engine-back-pressure measurements made at the three engine speeds investigated are presented in the following table:

Configuration	Engine back pressure (in. Hg)		
	At 1650 rpm	At 2000 rpm	At 2790 rpm
Unmodified exhaust system	2.5	3.5	3.5
Muffler alone	1.3	2.1	4.7
Muffler with long upturned tail pipe	1.7	2.4	...

The data show that at the two lower engine speeds both muffler configurations had smaller pressure drops than the unmodified two-manifold system. The reverse is true at 2790 rpm because no great increase in

back pressure occurs for the unmodified stacks above 2000 rpm. This fact may be due to a decrease in the component of back pressure due to sound waves although, since only one pressure tap was used in the tests, some question may arise as to the reliability of these values. Such a decrease has, however, been previously noted in reference 3. The back pressure for the muffler alone should be noted to be only about a third more than that for the unmodified configuration at this speed and, although data for the muffler with the long tail pipe are not available, the increase is estimated to be only slightly greater. Thus, although the back pressure for the muffler configuration is high, it is only moderately greater at 2790 rpm than that for the unmodified configuration being used in the test airplane, and it may be lower at other engine speeds normally used in flight. The horsepower output of the engine was determined from measurements made of the electrical output and the losses of the dynamometer motor. For 2000 rpm with full throttle, these measurements indicated that a gain of about 1 horsepower was obtained when the muffler with the long tail pipe was installed in place of the unmodified exhaust system. The slit exhaust cones on the unmodified stacks were found to produce a loss of from three to four horsepower. At 1650 rpm with full throttle, the power loss from the installation of the muffler and tail pipe was about $1\frac{1}{2}$ horsepower less than the power loss from the unmodified exhaust system. Due to insufficient cooling air, the cylinder-head temperatures rose rapidly to excessive values at 2790 rpm, and the output power variation with changes in cylinder-head temperature and inlet air temperature were so large that this variation could not be separated from the small power variations due to exhaust-system changes.

Flight Installation and Flight Tests

The muffler installation in the modified airplane is pictured in figure 8. The changes made in the manifolding may be seen by comparing this figure with figure 3. The path of the exhaust gas is from the engine through the manifolding to the common exhaust pipe below the airplane, back along the fuselage, up into the stretcher compartment, through the muffler, and out of the end of the tail pipe alongside, but at a safe distance from, the vertical tail. Because of the heat radiated inside the fuselage by the muffler, addition of a shield around the muffler through which cooling air was forced was necessary for the comfort of the pilot. (See fig. 9.) A photograph of the complete airplane, as flown in the demonstration, is given in figure 10. The results of the flight tests of this airplane, presented in reference 1, show that it was about 20 decibels quieter than the unmodified airplane at a distance of 300 feet from the observer.

The following facts were revealed by a comparison between the flight installation and the ground modified configuration, designated as muffler with long tail pipe. Both systems were made of the same diameter piping

behind the wye and were about equal in total length, except that in the ground installation the muffler was located relatively farther forward and, therefore, had a longer tail pipe. The manifolding of the flight installation was made of larger piping, and the bends all the way to the wye were of larger radius. The flight installation also had more bends in the exhaust piping and a slit exit which was not present on the ground installation. In view of these differences the noise spectrum of the flight installation is not expected to be exactly the same as that of the ground modified configuration, but the over-all noise level characteristics of the two installations may be expected to be quite similar, since the first-order attenuation characteristics in both cases depend upon the muffler. Analysis of the results of flight and ground tests reveals that they are indeed similar. The engine back pressure of the flight installation may be somewhat higher than that of the ground modified configuration due to the extra bends and slit.

SUMMARY OF RESULTS

An investigation of the attenuation characteristics of a muffler designed for the quiet-airplane demonstration tests revealed the following results:

1. The muffler alone reduced the engine over-all noise level by values ranging from almost 15 decibels at 1650 rpm to approximately 10 decibels at 2790 rpm. The addition of the long tail pipe with a right-angle bend gave a further reduction of about 5 decibels at some engine speeds.

2. Further reductions in over-all noise level of the engine appear possible only through the quieting of the intake and the engine-clatter noises.

3. The back pressures of the muffler installations were about a third higher than those for the unmodified test configuration at 2790 rpm and were lower at lower engine speeds. The power variations due to these back-pressure changes were small.

4. Some correlation between theory and experiment, with regard to the existence and location of cut-off frequencies and pass bands, appears possible despite excessive interfering noises and lack of instrument reading accuracy at low noise levels.

5. Results of ground and flight tests appear to check fairly well as to the order of magnitude of the over-all noise level.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., June 2, 1948

APPENDIX A

SYMBOLS

a	phase constant
a	radius of connecting holes, feet
b	attenuation constant
c	velocity of sound, feet per second $\left(\sqrt{1720\gamma T}\right)$
c_o	conductivity of entrance to outer chamber of filter $\left(\dfrac{n\pi a^2}{t + \dfrac{\pi a}{2}}\right)$
D_1	diameter of central tube, feet
D_2	diameter of outer chamber, feet
f	frequency, cycles per second
f_c	low-frequency cut-off, cycles per second
f_p	frequency of first upper pass band, cycles per second
k	wave length constant $\left(\dfrac{2\pi f}{c}\right)$
l_1	length of one chamber of filter, feet ($2l$ in appendix IV of reference 2)
m	number of chambers for which attenuation is calculated
n	number of connecting holes in entrance
p_m	sound pressure at entrance of mth chamber
p_{m+1}	sound pressure at exit of mth chamber
S	area of central tube, square feet
t	wall thickness of central tube, feet
T	temperature of exhaust gas, degrees Rankine
V_2	volume of outer chamber, cubic feet

W	phase and attenuation constant $(a + ib)$
Z	acoustic resistance of a plane wave in the central tube $\left(\frac{\rho c}{S}\right)$
Z_b	acoustic impedance of outer chamber $\left(i\left(\frac{2\pi f\rho}{c_o} - \frac{\rho c^2}{2\pi f V_2}\right)\right)$
γ	ratio of specific heats for exhaust gas
ρ	mean density of exhaust gas, slugs per cubic foot

APPENDIX B

METHOD OF MUFFLER DESIGN

Theoretical Assumptions

In the derivation of the equations presented hereinafter for the low-frequency pass muffler, the following conditions are assumed:

(1) Only plane pressure waves exist in the exhaust pipe

(2) The sound pressures are small compared with the absolute static pressure in the exhaust pipe

(3) Viscosity effects may be neglected

(4) The muffler walls neither conduct nor transmit sound

(5) No sound power is added in the muffler

(6) The muffler consists of an infinite number of identical chambers

(7) The conductivity c_o is large and is given with sufficient accuracy by the formula given in appendix A.

With conducting holes as small as those used in the muffler described (fig. 1), it is conceivable that viscosity effects at the holes may appreciably affect the conductivity. Also, since a practical muffler consists of a small number of chambers terminated by a tail pipe of finite length, the impedance at the outlet of a particular chamber in an actual case usually is not equal to the impedance which would be obtained with an infinite number of chambers beyond the outlet.

Design Equations

By definition, the attenuation of the mth chamber of an acoustic filter is

$$20 \log_{10} \frac{p_m}{p_{m+1}}$$

where p_m is the sound pressure at the entrance of the chamber and p_{m+1} is the sound pressure at the chamber exit. From appendix IV of reference 2,

$$\frac{p_m}{p_{m+1}} = e^{iW} = e^{ia-b}$$

where $W = a + ib$. The real part b represents attenuation, when it is negative; whereas the imaginary part ia represents a phase shift which is not required for calculating the numerical value of the attenuation.

Reference 2 also shows that, if one branch of an infinite series of identical branches is a pure reactance (no energy dissipation in the branch),

$$\cosh b = \pm\left(\cos kl_1 + \frac{iZ}{2Z_b}\sin kl_1\right)$$

The sign which makes the hyperbolic cosine positive is used, since for real values of b, $\cosh b \geqq 1$. When $|\cosh b| < 1$, no corresponding real angle b exists and, therefore, no attenuation is possible.

The attenuation of m identical chambers of an infinite filter is m times the attenuation of one chamber. From this information, the attenuation is found to be

$$20 \log_{10} e^{-mb} = -8.69mb$$

or

$$-8.69\, m \cosh^{-1}\left|\cos kl_1 + \frac{iZ}{2Z_b}\sin kl_1\right| \tag{B1}$$

where b is taken as negative since no sound power is added in the muffler.

Since no attenuation exists for $|\cosh b| \leqq 1$, the end points of the attenuation region may be found by setting $|\cosh b|$ equal to 1.

$$\left|\cos kl_1 + \frac{iZ}{2Z_b}\sin kl_1\right| = 1$$

Obviously, when $\sin kl_1 = 0$, $\cos kl_1 = \pm 1$, and the above condition is satisfied. The upper limit of the attenuation band may be approximately located by finding the lowest frequency, above zero, for which $\sin kl_1 = 0$. The upper limit is found to be

$$\frac{2\pi f l_1}{c} = \pi$$

If the upper limit of frequency for which attenuation is desired is known, the following relation can be used to fix the chamber length of the muffler.

$$l_1 = \frac{c}{2f_p} \tag{B2}$$

For the low-frequency cut-off f_c, the following formula is given in reference 2:

$$f_c = \frac{c}{\pi}\sqrt{\frac{S}{l_1 V_2}\left(\frac{1}{1 + \frac{4S}{l_1 c_o}}\right)}$$

This formula may be simplified if the number and size of the connecting holes are assumed to be such as to make $l_1 c_o \gg 4S$ (assumption (7)). This assumption is true of the filter shown in figure 1

$$f_c \cong \frac{c}{\pi}\sqrt{\frac{{D_1}^2}{{l_1}^2\left({D_2}^2 - {D_1}^2\right)}} \tag{B3}$$

This simplified approximate formula shows the effects of the basic filter dimensions on the low frequency cut-off. If the cut-off frequency is to be lowered, increasing the size of the outer chamber is obviously necessary, since the exhaust gas temperature and back-pressure limitations set the values of c and D_1.

Application to Design

In the application of the equations to the design of a muffler, analyses of the engine noise such as are shown in figure 7 are customarily obtained first. The lowest frequency which must be attenuated, and usually the loudest, is ordinarily the engine firing frequency. (See fig. 7.) The cut-off frequency f_c is chosen slightly below this frequency. Another frequency is found on the spectrum analysis above which no attenuation is required. The pass frequency f_p is chosen slightly above this frequency. The diameter of the central tube D_1 is determined to meet the back-pressure requirements. Then l_1 and D_2 are found by use of the approximate formulas (B2) and (B3). The dimensions are finally substituted in equation (B1) and the attenuation is calculated

for a single chamber $(m = 1)$. A sufficient number of chambers is then chosen to insure satisfactory attenuation at all frequencies. Since both the inlet and the outlet of the muffler are pipes of finite length, resonances in them should be carefully avoided. Although a muffler of this type has been shown to provide satisfactory engine-exhaust noise reduction, it is not necessarily the smallest or most efficient muffler which can be designed for a particular engine.

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3. Martin, Herbert: Muffling without Power Loss in the Four-Stroke-Cycle Engine. Translation No. 328, Materiel Div., Army Air Corps, Aug. 3, 1938.

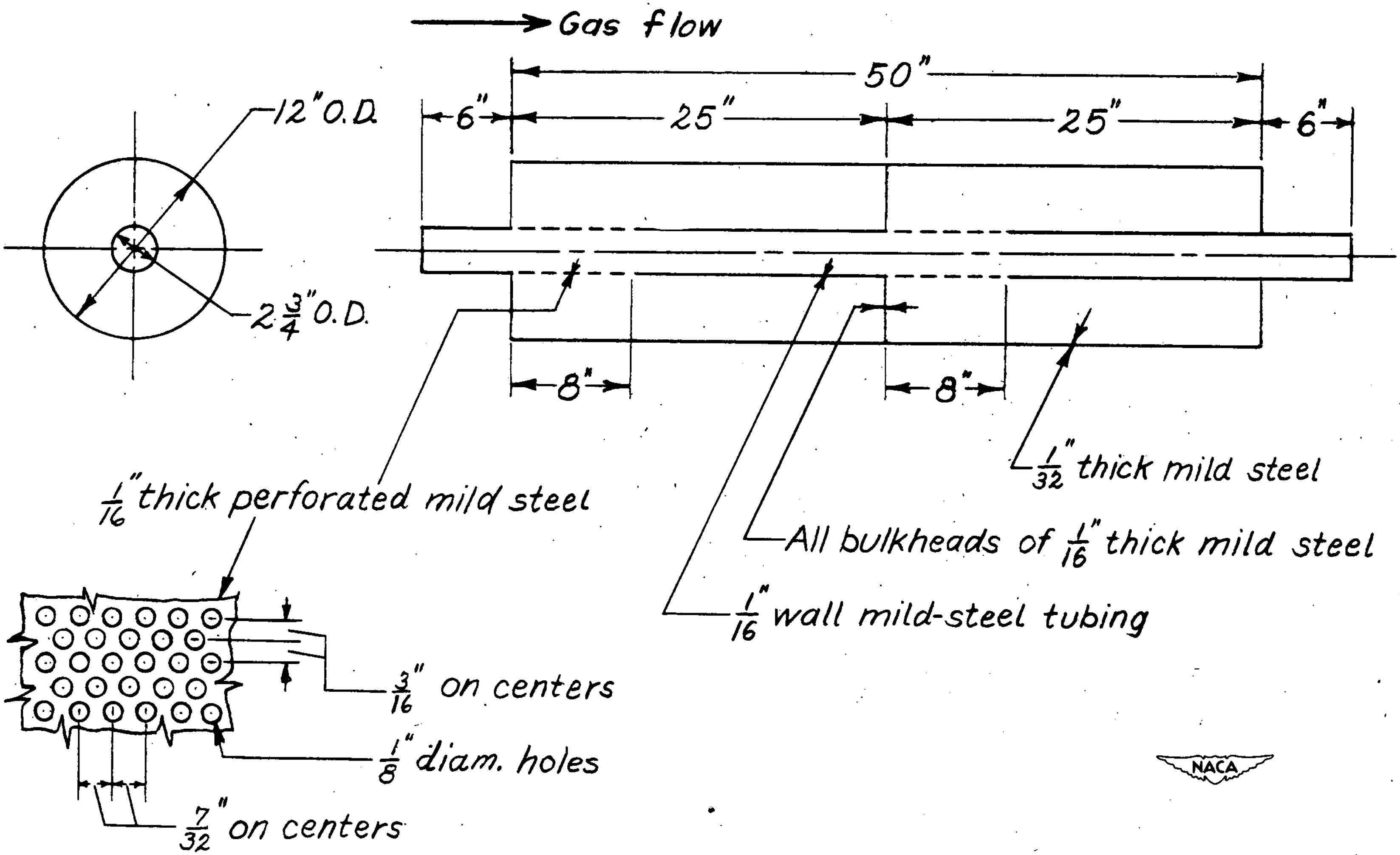

Figure 1.– Details and dimensions of muffler designed for flight installation on typical six-cylinder light-airplane engine. All welded construction.

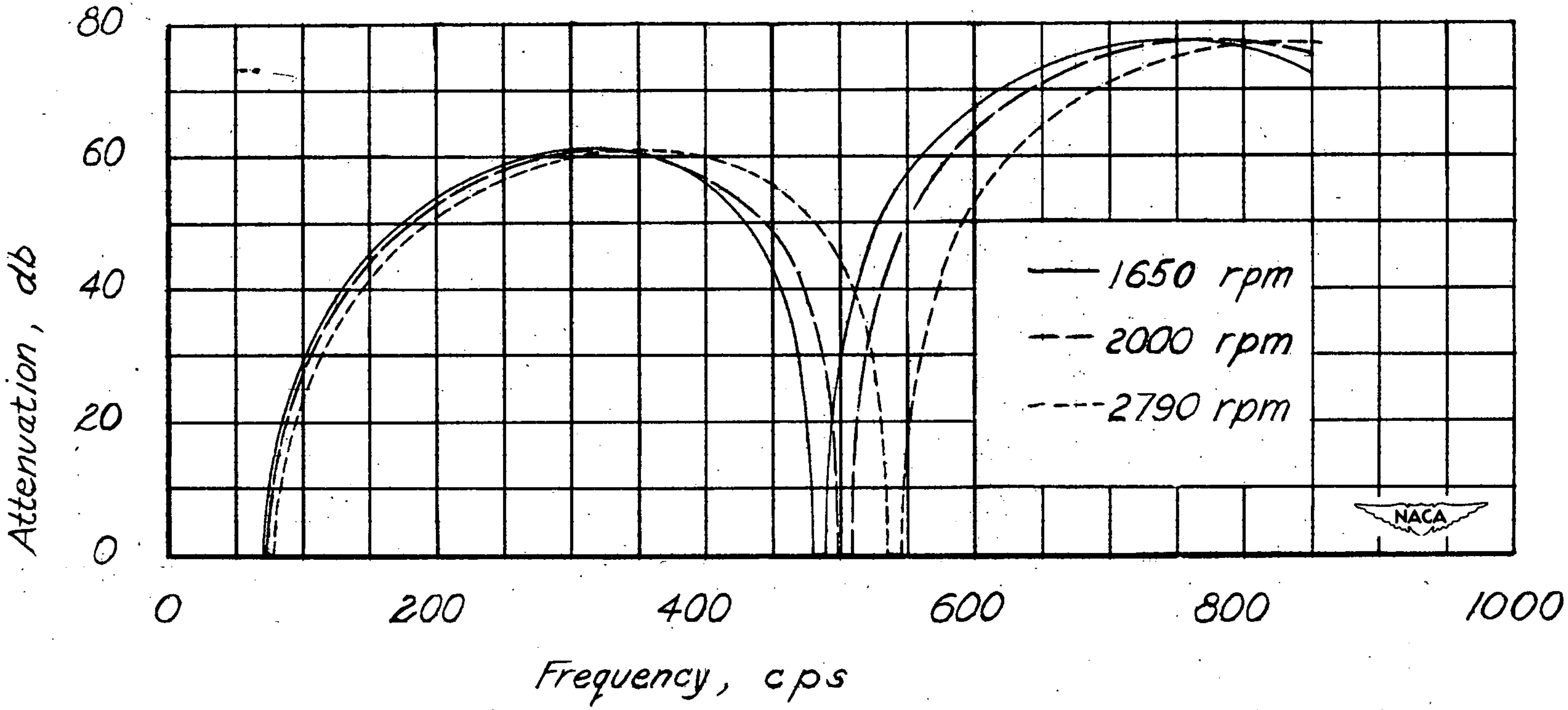

Figure 2.- Calculated attenuation characteristics of muffler designed for flight installation on test engine.

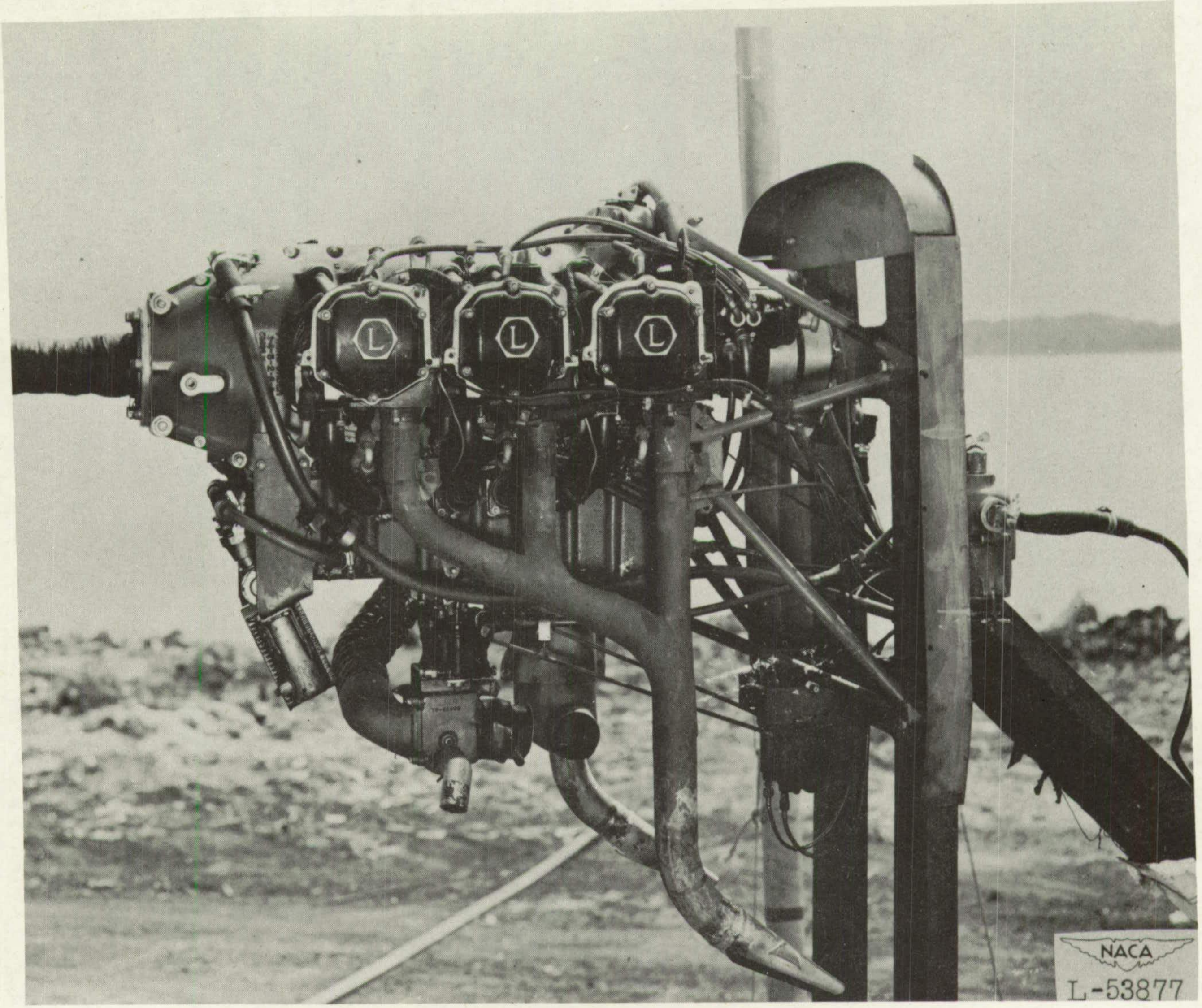

Figure 3.- Exhaust system of unmodified test airplane.

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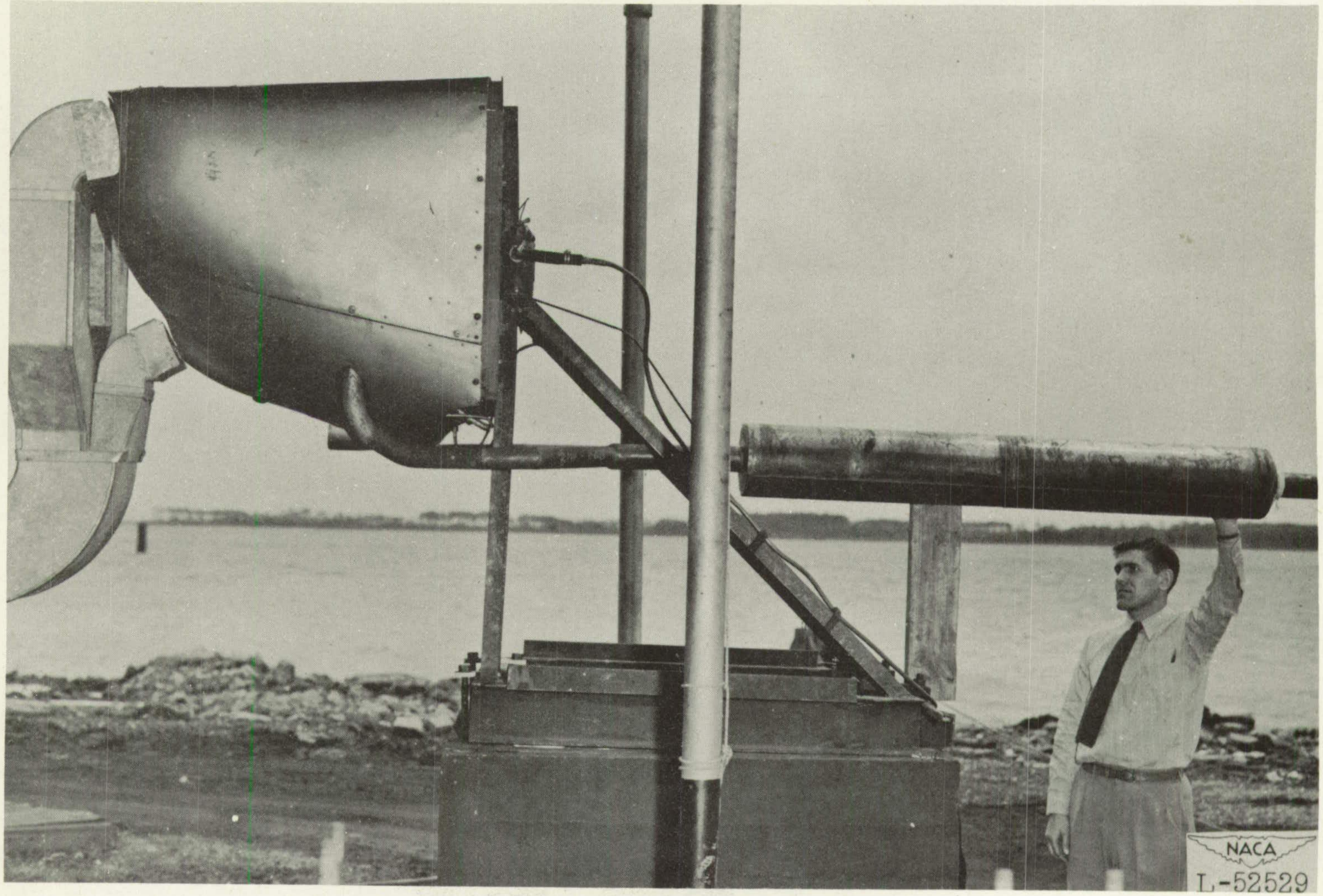

Figure 4.- Side view of engine with a test muffler (not the one described herein) attached.

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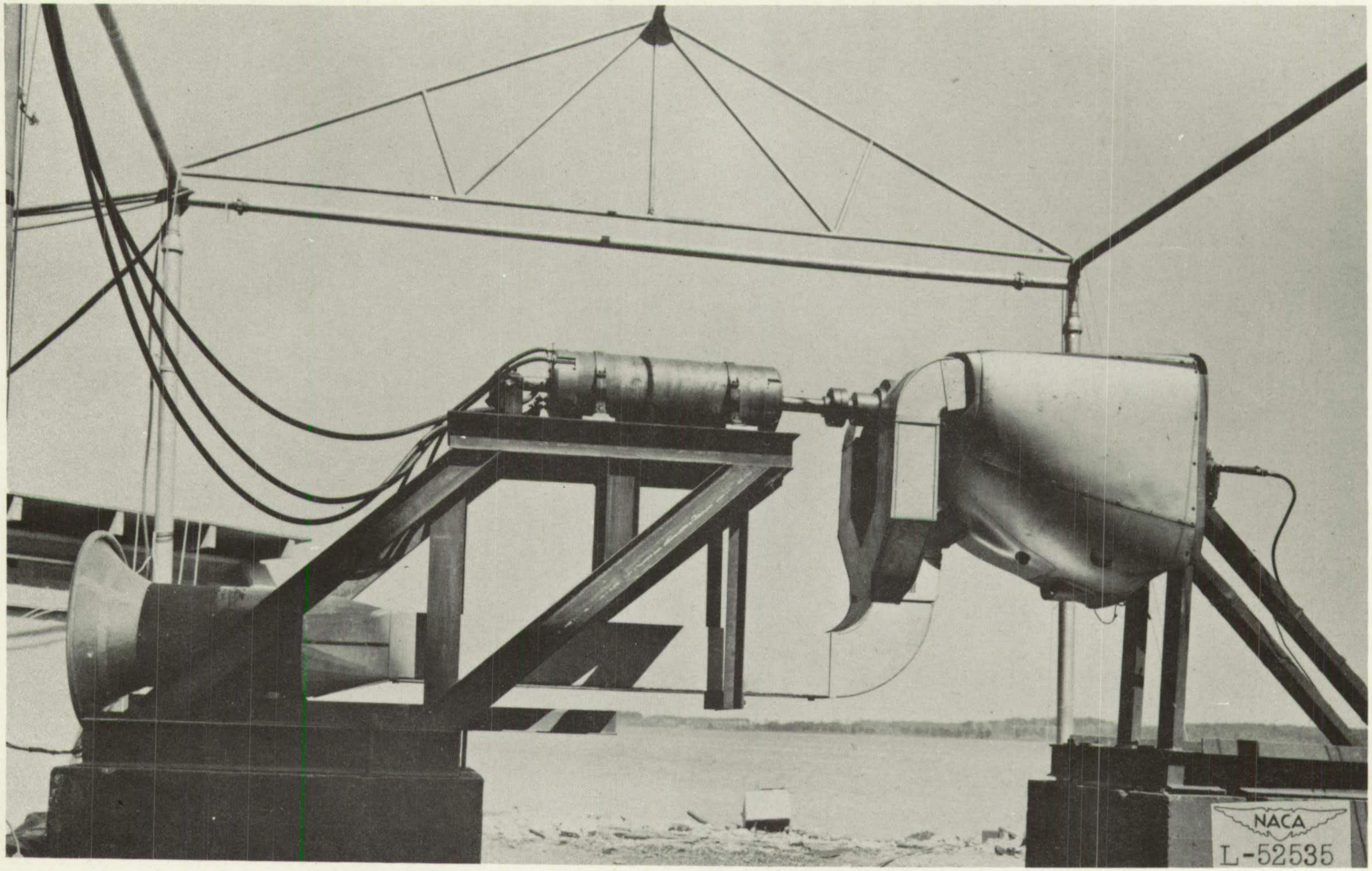

Figure 5.- Side view of dynamometer setup at the Langley full-scale tunnel.

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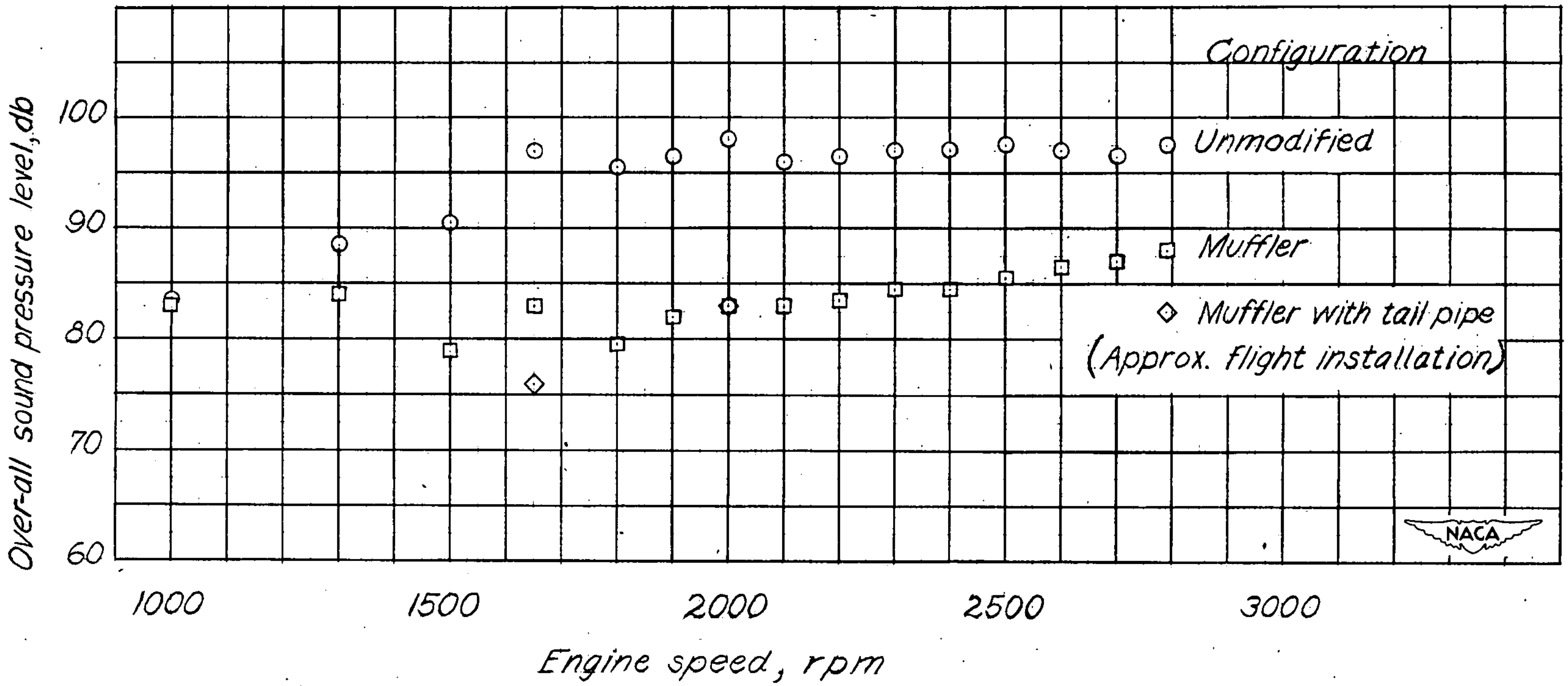

Figure 6.- Attenuation in over-all noise level due to muffler installation on test engine.

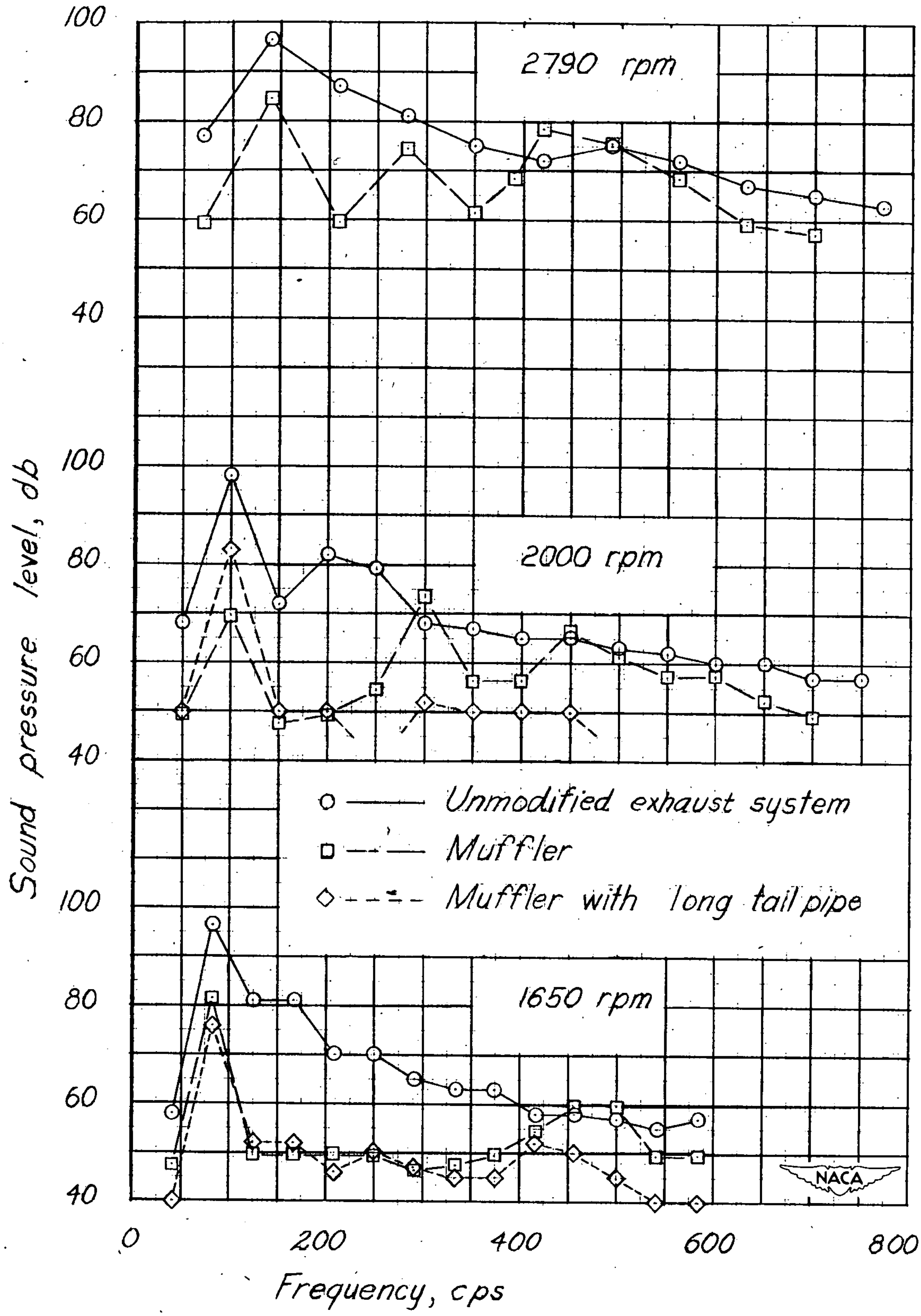

Figure 7.- Noise spectrums for the test engine.

Figure 8.- Muffler installation in modified test airplane.

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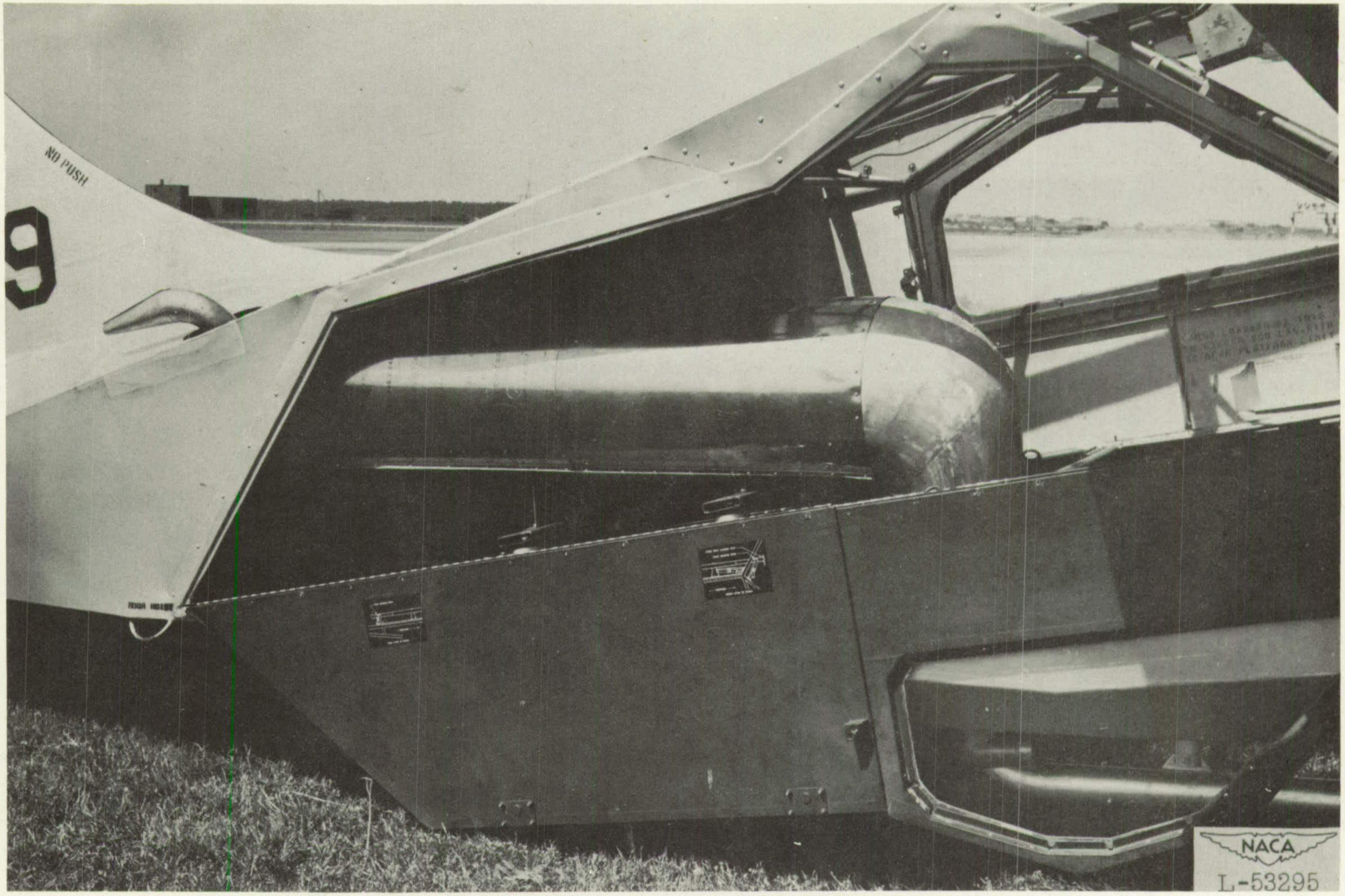

Figure 9.- Muffler installation with shield which was placed around muffler.

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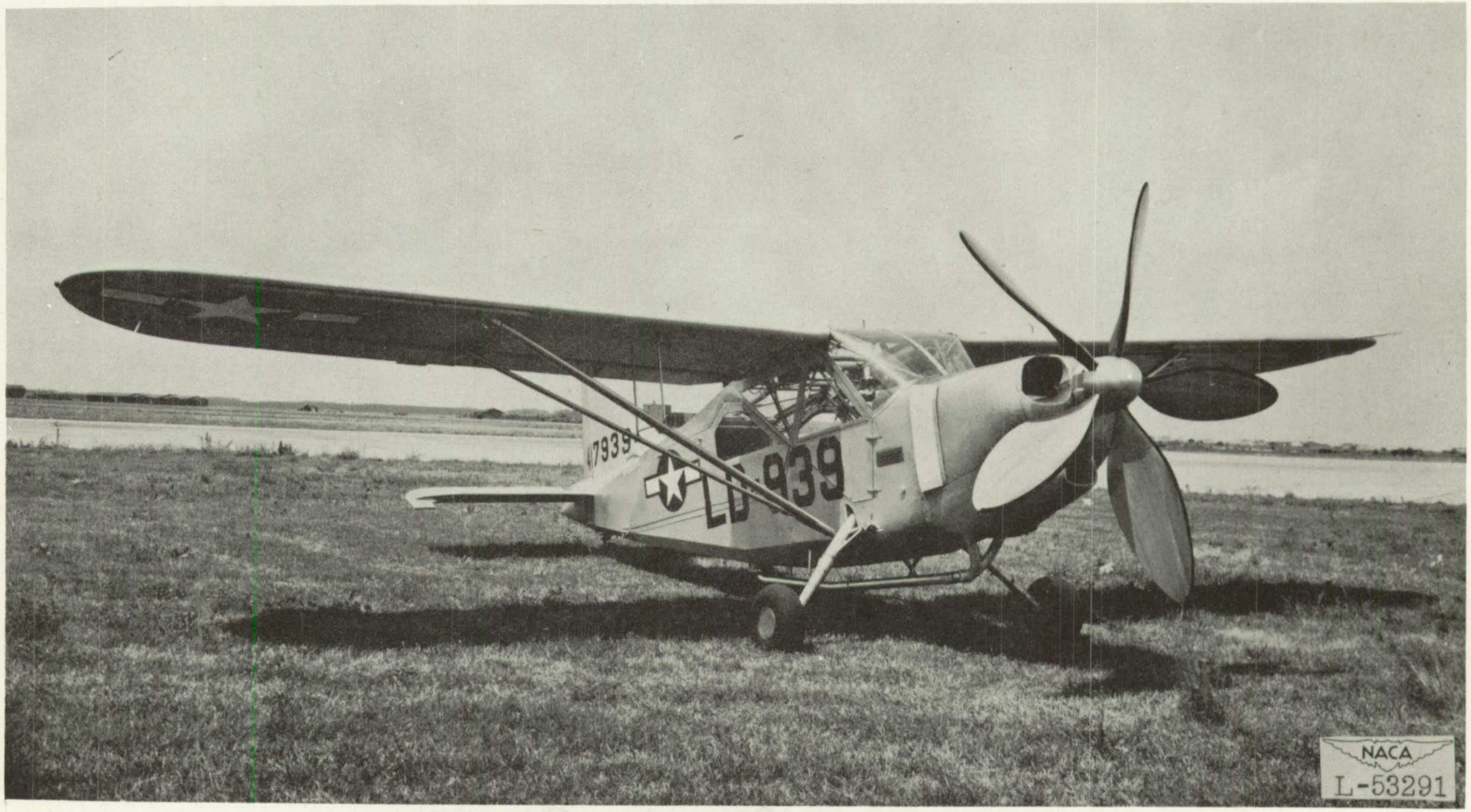

Figure 10.- Modified test airplane as flown in flight demonstration.